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DEVELOPMENT OF THE DEMPSTER HIGHWAY NORTH OF THE ARCTIC CIRCLE

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HIGHWAY NORTH OF THE ARCTIC CIRCLE

by

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Public Works Canada
Western Region

for presentation at the

THIRD INTERNATIONAL CONFERENCE
ON PERMAFROST

in

EDMONTON, ALBERTA - JULY, 1978

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DEVELOPMENT OF THE DEMPSTER HIGHWAY

SOUTH OF THE ARCTIC CIRCLE

ABSTRACT

Construction of the Dempster Highway in the Yukon and Northwest Territories was accelerated in 1971 and is slated for completion in 1979. The authors were intimately involved in the design and construction of the highway during the entire period and have endeavoured to highlight their experience during this activity.

The Design Criteria, Pre-engineering Activities, Construction Techniques and Road Performance are treated in some detail and should be of interest to any agency contemplating similar engineering/construction activities in comparative Regions of Canada North. They have also identified needs for further research and experimental work in the interest of advancing engineering knowledge as related to highway construction in extreme Polar climates.

DEVELOPMENT OF THE DEMPSTER HIGHWAY

NORTH OF THE ARCTIC CIRCLE

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INTRODUCTION

Public Works Canada, on behalf of the Department of Indian Affairs and Northern Development has acted as the engineering construction agency in the development of the Dempster Highway; in the Yukon and Northwest Territories, over a distance of 458 miles (740 km), connecting the communities of Inuvik, N.W.T. on the northern end and Dawson, Y.T. on the "south" and joining the communities of Arctic Red River and Fort McPherson along the way.

The initial 35 mile (56 km) contract south of Inuvik Airport was awarded in 1971, three other contracts of similar length were awarded since that time covering the entire portion of the route within the Northwest Territories (168 miles) (270 km). Comparative concurrent progress was experienced from the Dawson end. The route is now scheduled for completion within 1979, with initial access in 1978.

(Illustration Map)

HIGHWAY STANDARDS

The highway is being constructed to an "all weather" non-paved surface, subject to spring thaw and fall freeze-up periods due to loss of the ice ferry crossings respectively over the Peel, Mackenzie and Arctic Red Rivers. Subgrade surface widths vary between 24 and 28 feet (7.3 and 8 m). Travel speeds of 50 to 60 m.p.h. (80 to 95 km/hr) will be possible, except for loaded trucks in areas where gradients exceed the objective maximum of 6%, occasionally by as much as 4% (10%) within mountainous topography. Side slopes are generally 3 to 1.

(To be illustrated with appropriate slides)

DESIGN CRITERIA

Since this project was the first large scale highway to be developed at this latitude in North America we had very little documented experience of an engineering nature that could be applied directly to the site conditions prevalent along the route particularly in the low relief region adjacent to the Mackenzie Delta where glacial activity left behind a thick mantle of ice rich till without any deposits of suitable common (granular) borrow.

Our prime concern was to preserve the permafrost to a tolerable degree of grade distortion. In keeping with this concern our design objectives were to provide for uninterrupted cross drainage during expected embankment settlement/distortion caused by thermal degradation; to locate suitable thaw stable construction materials which would provide a structurally competent highway section

requiring minimal surfacing materials due to their short supply.

EMBANKMENT DEPTH

The initial design concept/objective was to establish the minimum depth of fill which would prevent advance of thaw into ice rich inorganic soil, i.e. to limit the depth of thaw to the original ground surface, or within the active organic layer.

Assuming winter construction, the saturated surface organic layer when frozen would act as a "heat sink", however, once thawed under a fill, compression of the peat and organics would occur, minimizing the heat sink, reducing the natural insulating properties, and allowing the thaw plane to migrate deeper in succeeding summers.

The major problem was considered to be within embankment side slope zone where fill cover would be minimal, allowing the thaw plane to extend early into, and through the organic and peat cover, resulting in progressive thaw and subsidence. However, this "critical" zone would be a narrow band along each side of the highway and it was considered it would "self-heal" in possibly three to four years with only slow slumping of the 3 to 1 side slope embankment material. Minor loss of shoulder support was assumed tolerable, and could be repaired during normal maintenance. Major surface distortion and repair would occur only if the thaw zone extended into ice-rich mineral soil over the entire road width.

A review of experience at the Inuvik Airport revealed maximum thaw depths of 80 to 90" (110 cm) into a gravel and quarried rock embankment.

Based only on thermal conductivity of materials (BTU/HR/Sq.Ft./°F) the value for shale (our major embankment source), is roughly 60% of that for quarried rock, thus suggesting a design embankment height using shale, of 4 to 4.5 feet (1.4 m).

Thaw advance was evaluated by a mathematical model using the finite element method, with 2', 4' and 6' of shale and silty clay embankments under a set of thermal conditions which would produce an average depth of thaw (18") equal to the active layer for the Inuvik area. This analysis suggested no apparent advantage in fill heights greater than four feet for thermal protection purposes. Further analysis also indicated the depth of 4 to 5 feet would likely stabilize after five years.

Based upon these theoretical calculations plus performance observations of the Inuvik Airport Road (8 miles) which was constructed some 15 years earlier, the final design called for a minimum fill height of 4.5' (1.4 m).

DRAINAGE

As was subsequently confirmed during construction, it was also felt that special attention had to be given to the provision of reliable cross drainage in areas of ice rich fine grained soil, particularly to avoid runoff along the thermally disturbed toe of embankment zone which would contribute to rapid degradation of permafrost.

The unusual conditions which had to be accommodated were:

- The absence of historical hydrological data

- Poorly defined drainage basins
- A thaw unstable subgrade, that would degrade and settle to undeterminable random degrees after culvert placement
- Rapid, short term spring runoff over the frozen saturated tundra, i.e. no evaporation or infiltration
- The thermal anomaly of a culvert (hole) through a shallow, shifting embankment
- The tendency for complete ice filling of small culverts prior to spring runoff

In response to the above conditions it was decided that:

- The minimum culvert size would be 30 inches (77 cm) in diameter
- Culverts had to be capable of withstanding considerable distortion, i.e. be flexible - the corrugated metal type
- Culvert inverts would be located at, or even slightly above, the average entrance ground elevations
- We would endeavour to err on the high side in terms of size until sufficient hydrologic data was obtained and local runoff characteristics were better understood
- At locations requiring pipes greater than 60 inch (154 cm) diameter, smaller relief pipes would be installed and/or steam pipes easily accessible from the road, would be installed as an integral part of the facility to permit thawing of ice-full culverts as spring approached.

HIGHWAY LOCATION AND EMBANKMENT MATERIALS

Due to the predominance of ice rich fine grained thaw unstable surficial soils in the region, an important criteria in location was to avoid areas requiring excavation, i.e. contrary to construction in non permafrost regions low lying flat ground was a highly desirable topography which would facilitate meeting standards of geometrics, reduce quantities, and more easily accommodate the overlay (end dumping) method of embankment development as way of reducing environmental impact and permafrost degradation.

The design/location for the first two contracts did not place sufficient emphasis on the above objectives. Also due to implied economics (i.e. prices for "common" vs rock excavation) several "drier" fine grained borrow sources were specified. Shortly after the start of construction with these materials it was revealed that even these sources were inadequate and it became obvious that the entire project, particularly that section adjacent to the Delta and up to the point where the highway is well within the Richardson Range; would have to be constructed with quarried shale or sandstone rock.

SURFACING

The need to use quarried materials within the embankment and the resultant increased cost of this subgrade was significantly offset by the reduced thickness of granular base and surfacing requirements (i.e. 2 to 3 inches vs 10 to 12 inches) (5 up to 25 cm). With only two gravel sources available within the 168 mile stretch in the Northwest Territories, the majority of surface materials

had to be manufactured by quarry and crushing of limestone, sandstone and dolomite limestone deposits.

THAW UNSTABLE CUT TREATMENT

Since the surficial soil types and conditions in this region are not suitable for embankment construction, the highway location and grade line design, avoided excavation wherever possible. Therefore, due to the infrequent occurrence of thaw unstable backslopes, (one large cut in 120 mile section) and in keeping with our basic objective to minimize environmental impact (aesthetics) our general rule was to blanket any thaw unstable backslopes with quarried rock. The area within any cut requiring such treatment was determined by recording sections of instability during the first summer season following excavation. As a case in point, the large cut at Mile 343 required blanketing of only 5% of the facial area at a cost of approximately ten dollars per facial square yard, ($\$12/m^2$), where treatment heights varied from 15 to 30 feet (4.6 to 9.1 m).

PRE-ENGINEERING ACTIVITIES

(a) Geology

Between Inuvik and Arctic Red River the surficial geology consists largely of an undifferentiated till plain with cretaceous shales at depths of 5' to probably 100' (3 to 30 m). Near Inuvik there are outcrops of shales and dolomites, and at Arctic Red River, outcroppings of shales and sandstone. Between Arctic Red and Fort McPherson the terrain is largely hummocky moraine (till) with large areas of lacustrine and organic deposits. Bedrock exposures at Fort McPherson are shales and some interbedded sandstone. West

of Fort McPherson the terrain generally reflects the underlying bedrock strata as the route ascends towards the Richardson Mountains. The entire area in this foothills region is overlain by erratic unconsolidated sediments, largely hummocky moraine. The Richardson Mountains are composed primarily of shales and siltstones with some ridges of resistant sandstone. Over the entire length of the Dempster there are occasional random glacial-fluvial deposits.

(b) Geotechnical Investigation

Airphoto interpretation was utilized initially to evaluate the terrain and preselect potential borrow sites. Initially, bedrock outcroppings, glacio-fluvial deposits, partially sorted deposits such as kames, and till ridges were selected for test drilling. When all fine-grained deposits proved to be unsuitable as embankment material because of excess ice, field investigations were concentrated upon locating bedrock within shallow overburden or granular deposits. Glacio-fluvial deposits proved to be erratic, containing large ice blocks that limited usable quantities. Few such deposits were considered suitable for embankment development thus limiting borrow sources largely to bedrock outcroppings, or areas of shallow overburden (i.e. stripping of less than 8 to 10' (2.5 to 3 m). Such sources were located for the most part at regular intervals along the alignment. Maximum haul distance was 10 miles (16 km) and the average for the highway was in the order of 4 miles (6.5 km).

All field borings were carried out with high speed rotary rigs using carbide insert bits and compressed air as a drilling medium. Virtually all soil samples taken were disturbed "grab" samples -

initially some problems were encountered in relating laboratory test data on these highly disturbed samples to in-site conditions, particularly as to ice content. However, with experience and increased sampling frequency good success was achieved.

Drilling programmes generally consisted of 5 to 6 holes on center-line per mile plus an average of 10 holes per mile (7/km) during borrow search. Exploration programmes were carried out during the winter to avoid environmental damage using tracked vehicles, mobile camps and helicopter support.

CONSTRUCTION TECHNIQUES

Due to the high water (ice), and silt fraction predominant in the surficial soils, the majority of the highway embankment within the Northwest Territories was constructed from shale and sandstone quarried rock. These, relatively weak rock types were usually excavated using large tractor ripping equipment. Some Contractors, particularly those who specialized in rock operations preferred to drill and blast prior to ripping and loading using ammonia nitrate explosives in widely spaced hole patterns. The other prime movers of embankment materials usually consisted of large front end loaders, a fleet of large trucks and a bulldozer at the dump site to spread the delivered volumes in 2 to 2½ foot lifts. Grid compactors were used only on the final grade. Adequate densities were obtained for this class of road using dry rock materials, by the normal tracking of prime movers on the shaped embankment. Use of compaction equipment on the final grade surface was deployed not only to obtain a tighter surface, but equally important, to breakdown the large

fractions as delivered from a quarry operation to facilitate construction traffic and subsequent gravel surfacing operations.

All contractors chose to work the year round except for about a two month break between December 15 and mid-February. As would be expected, performance and production was lower during the winter months due to loss of efficiency of labour and equipment. However, tracking and forward mobility of the prime movers was easier over frozen ground.

As mentioned previously, in the interest of least impact (tundra disturbance) Contractors were obliged to build from borrow source to borrow source during summer months. Under winter conditions the haul from borrow was halved, since tracking of the excavation and haul units was permitted to move over the frozen tundra to the next pit after reaching the economical haul point between sources. Removal of waste (stripping) material was much easier in their frozen state due to the high ice content and therefore thaw unstable conditions of these horizons. In the areas of deep overburden on borrow deposits, the development of material sources tended to be small in area but relatively deep with generally greater spacing of approximately six miles between sources. Such operations tended to be much more suitable for truck and loader operations. In the mountain areas where overburden was shallower and deposits were spaced closer, motor scrapers provided an alternate approach but were not frequently chosen by Contractors. Installation of drainage facilities were also found to be easier in the winter, since ground seepage and surface waters could be "frozen off" from the installation area. Prudent Contractors

took advantage of summer and winter construction by careful scheduling of their operations. Since freight access to the project was only possible during the navigation season of the Mackenzie River (June to September) careful analysis of types and numbers of construction equipment required for efficient execution of the work had to be made prior to initial mobilization.

SURFACE TREATMENT

Initial highway usage indicates that surfacing requirements on the predominantly shale bedrock material is more critical for traction than for structural requirements. Relatively light applications (2 to 3 inches) of granular surfacing was found to be adequate.

The near total lack of granular deposits in the delta area has necessitated the use of quarried limestone for the production of surfacing materials. This, together with poorly graded granular materials in others, has frequently required the addition of fine-grained materials as a binder in the surfacing operation. Mixing of the granular surfacing with the weather surface of shale bedrock embankments has been a common solution to this problem. On the average a ratio of three parts "gravel" to one part decomposed shale produced the best results.

Because of differential settlement and warping of most sections of embankment during the early years, surfacing was delayed by 2 to 3 years to allow for subsidence and warping of the embankment due to thermal degradation.

ROAD PERFORMANCE

The degree of embankment settlement and distortion varied considerably over the project length. Naturally, where the ice content was high within the thaw zone, settlement of the fill was greatest due to consolidation and displacement of such ground conditions. Sections built during the winter distorted more than those constructed during the summer since displacement of the soft, saturated insitu ground and tundra took place during spreading of the initial embankment lift.

Figures 1 and 1a illustrate the distortion vs. time relationship for a section of the highway constructed primarily during freezing conditions. The "reasonable travel speed" values were obtained by travelling over the embankment with a pickup truck unit. The occurrence of these values were calculated as a percentage of the sections length (frequency) as shown on figure 1. The average travel speed was calculated and is also shown on this figure. On figure 1a the average travel speed was related to the design (objective) speed and plotted versus time. The highway grade was repaired between readings during the fall, to an overall average speed equal design speed (60 m.p.h.). The resultant plot shows the degree of distortion in the early life of the embankment, suggests that thermal degradation reduces with time and that by year four after construction the thermal regime has reached equilibrium for practical purposes. The conditions/relationships portrayed on these figures (1 and 1a) are those obtained on a 30 mile section south of the Inuvik airport. The performance of this section in terms of distortion magnitude was the poorest

figure 1.

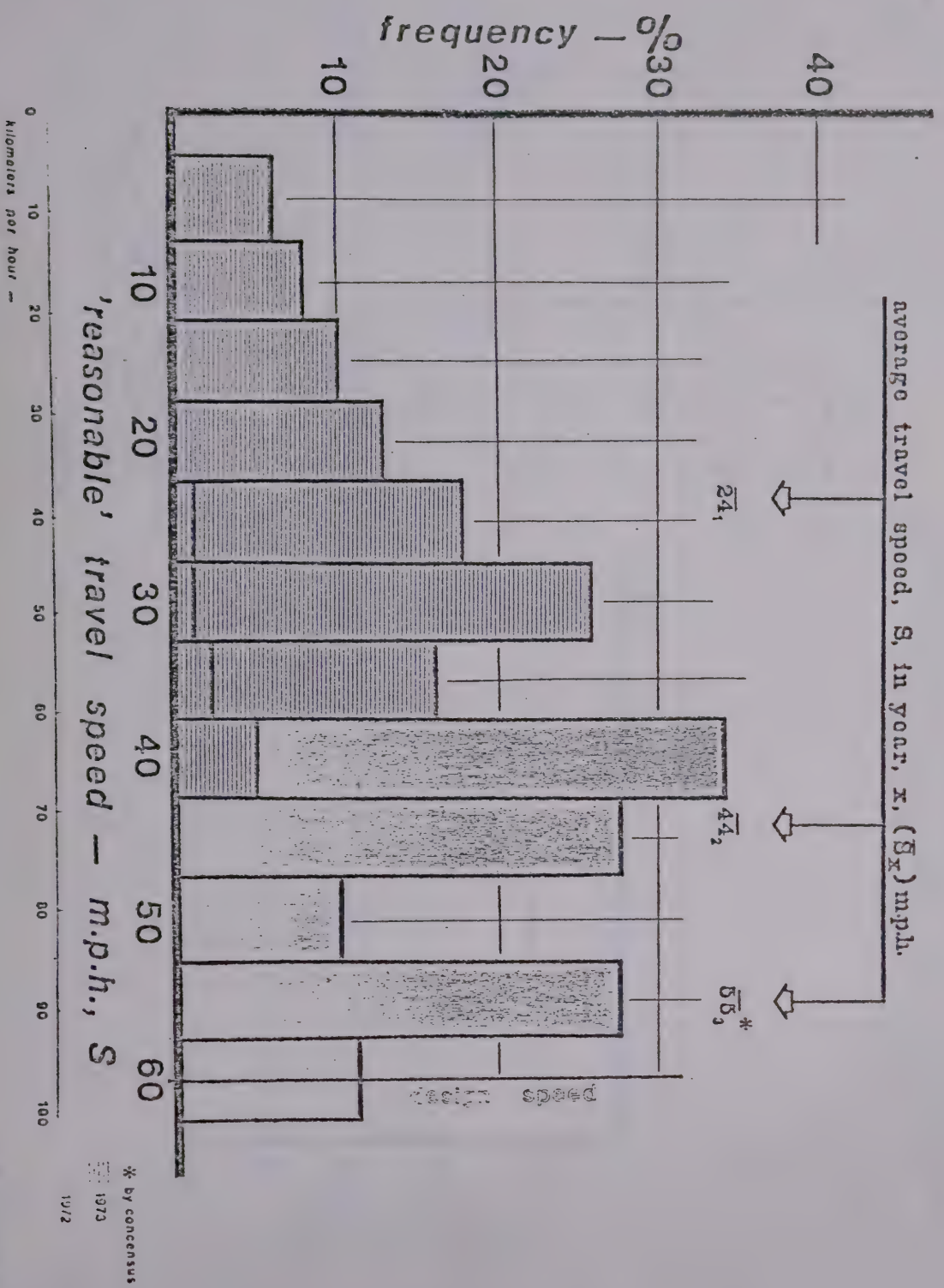
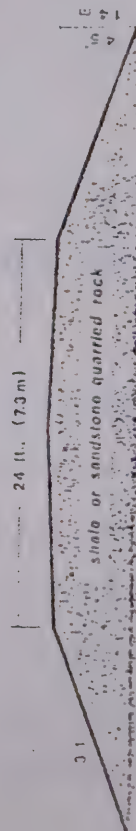
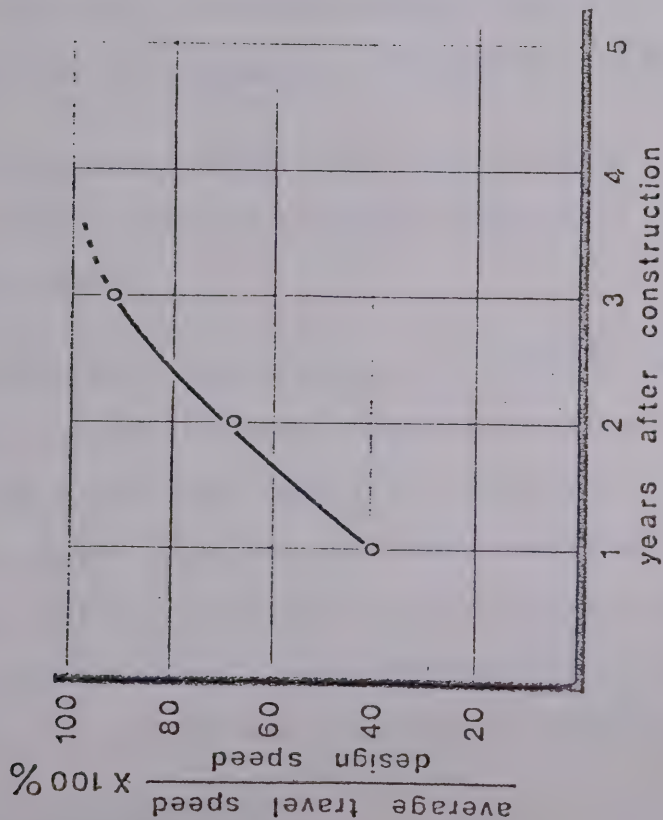


figure 1a.

climate

- yearly mean temp. 26°F (-4°C)
- precip., 9.14 ins. (23 cm), 80% snow
- F° days - freezing, 8200
- F° days - thaw, 2200



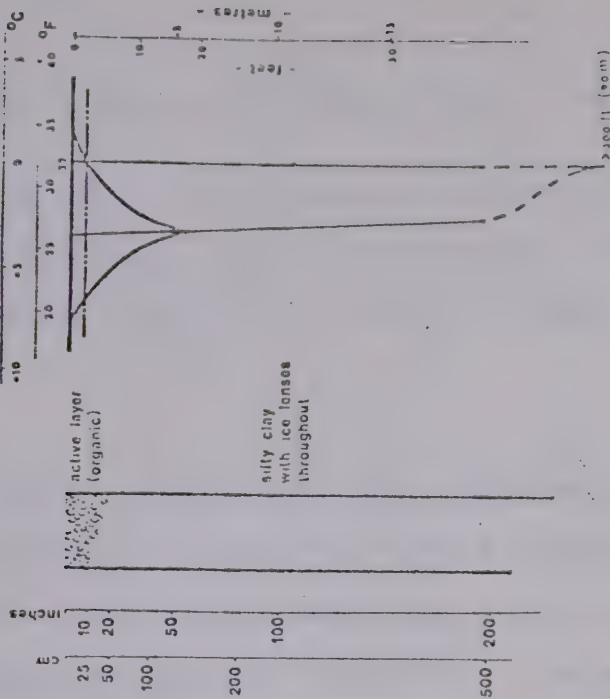
typical road section

general soil conditions

active layer (organic)

silty clay with ice lenses throughout

typical, undisturbed thermal regime



encountered in the 170 miles constructed in the Northwest Territories.

The installation/performance of culverts presented unique problems, requiring "reverse" camber at times, subexcavation and/or artificial insulation in areas of particularly high ice content ground.

RESEARCH STARTED

Several sections of the highway incorporated styrofoam insulation in 1972/73. Although the thickness of insulation varied between 3 and 4½ inches all treated sections were successful from a surface observation standpoint, i.e. the embankment did not settle. These sections were instrumented and have been monitored continuously with all data submitted to the National Research Council. A detailed report will be presented by this agency at some future date.

One section was treated with foamed sulphur (5 inches thick) in 1974. This section was equally successful in preventing thaw below the embankment.

Due to high cost implications ($\$1.25/\text{ft}^2$) and considering the low category (gravel surface) road involved we have adopted a posture, regarding artificial insulation, that roads at this latitude would be constructed initially without insulation. The performance would then be monitored and the highway maintained by conventional means, i.e. insulation would be used only when it was clear that normal maintenance was too costly or impractical for other reasons.

FURTHER RESEARCH NEEDS

1. Obtain more accurate costs of artificial insulation.

2. Study the implications and problems associated with long term settlement resulting from thermal degradation.
3. Determine more effective and economic methods of culvert de-icing including possible means of avoiding icing of culverts and upstream glaciation.
4. Determine the most effective means of controlling thermal degradation at the toe of embankment. For example, would the construction of berms along the toe be more effective than our present approach, providing flat sideslopes.
5. Determine whether flat sideslopes (say 3 to 1); or $1\frac{1}{2}$ to 1 sideslopes with berms at the toe of embankment are more effective in reducing thermal degradation at this critical point.

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